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SEPTEMBER 28, 1967 ni

MISSION AS-501 SEPARATION AND RECONTACT ANALYSIS

By Mission Simulation Department
TRW Systems Group
and
Flight Studies Section
Flight Analysis Branch
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MISSION PLANNING AND ANALYSIS DIVISION
MANNED SPACECRAFT CENTER
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FOREWORD

This report is a comprehensive volume including a summary of all separation studies relating to Mission AS-501. It is submitted to the NASA/Manned Spacecraft Center by TRW Systems as a part of Task MSC/TRW A-122, Separation and Recontact Analysis for Apollo Missions, of the Apollo Mission Trajectory Control Program under Contract NAS 9-4810.

CONTENTS

ILLUSTRATIONS

1. INTRODUCTION

This report is a comprehensive volume of separation and recontact analyses for Mission AS-501. The purpose of the AS-501 mission is to demonstrate the structural compatibility of the launch vehicle and spacecraft and to verify the adequacy of the Block II heat shield when subjected to lunar return velocities.

This report serves as a reference to past AS-501 separation and recontact studies and provides the additional studies necessary to complete the AS-501 separation and recontact analysis.

A summary of all separation analyses is presented in tabular form, and discussion of significant results and appropriate references are also provided.

2. SUMMARY OF SEPARATION ANALYSES

A summary of all separations and possible recontact problems for Mission AS-501 is presented in Table 1. References, recommended procedures, and comments are provided where appropriate.

CSM/S-IVB recontact is imminent for aborts during the ascent to orbit phase in which there is no SPS ignition. This condition is possible during the following:

- Launch Phase, No SPS Burn Aborts
- Mode II Aborts
- Mode III Aborts

The problem of recontact can be eliminated for all of these aborts by commanding the S-IVB ullage off at time base (TB) 5. TB5 begins at first S-IVB burn cutoff.

CM/SM recontact during the entry phase cannot be completely ruled out for those entries in which the ratio of SM to CM ballistic coefficients is between 0.88 and 1.16. This may occur during the following:

- The nominal mission
- Alternate missions resulting from contingencies during the second S-IVB burn
- Mode III Aborts
- Aborts during the second SPS burn

However, for recontact to occur, the SM must fail to spin up and must trim with its lift vector up in the orbital plane, and the CM must fly a lift vector down 10g controlled trajectory or a rolling entry in the case of Mode III aborts. Presented in Reference 3 is a complete analysis of CM/SM separation during the entry phase for the nominal, alternate, and aborted missions of AS-501.

Table 1. Mission AS-501 Separation and Recontact Study

Mission	Separation	Recontact Possibility	References	Discussion	Recommended Procedures or Comment
Nominal Mission	CSM/S-IVB	no	2	Section 3. 1	
	CM/SM	yes	3	Section 3. 2	Recontact is improbable, but cannot be completely ruled out.
Alternate Missions (Mode IV Aborts)					
Alternate Missions During First S-IVB Burn	CSM/S-IVB	no		Section 4. 1. 1	
	CM/SM	no	3	Section 4. 1. 2	
Alternate Mission During Parking Orbit	CSM/S-IVB	no		Section 4. 2. 1	
	CM/SM	no	3	Section 4. 2. 2	
Alternate Missions During Second S-IVB Burn	CSM/S-IVB	no	2	Section 4. 3. 1	
	CM/SM	yes	3	Section 4. 3. 2	Recontact is improbable, but cannot be completely ruled out.
Aborted Missions					
Launch Phase, No SPS Burn Aborts	CSM/S-IVB	yes	10, 11	Section 5. 1. 1	S-IVB ullage should be commanded off at time base five.
	CM/SM	no	3	Section 5. 1. 2	
Mode II Aborts	CSM/S-IVB	yes	10, 11	Section 5. 2. 1	S-IVB ullage should be commanded off at time base five.
	CM/SM	no	3	Section 5. 2. 2	
Mode III Aborts	CSM/S-IVB	yes	10	Section 5. 3. 1	S-IVB ullage should be commanded off at time base five.
	CM/SM	yes	3	Section 5. 3. 2	Recontact is improbable, but cannot be completely ruled out.
Aborts During Parking Orbit					
SPS Deorbit	CSM/S-IVB	no		Section 5. 4. 1. 1	
RCS Deorbit	CSM/S-IVB	no	9	Section 5. 4. 1. 2	
	CM/SM	no	3	Section 5. 4. 2	
Aborts During Second S-IVB Burn	CSM/S-IVB	no	2	Section 5. 5. 1	
	CM/SM	no	3	Section 5. 5. 2	
Aborts During SPS Burns	CM/SM	yes	3	Section 5. 6	Recontact is improbable, but cannot be completely ruled out.
General Studies					
SPS Plume Effects on S-IVB	CSM/S-IVB	no	14	Section 6. 1	
S-IVB Overspeed	CSM/S-IVB	no	9,	Section 6. 2	
G and N Failure	CM/SM	no		Section 6. 3	

3. NOMINAL MISSION

The nominal mission is described in Reference 1.

3.1 CSM/S-IVB SEPARATION

Reference 2 presents vehicle separation data for the AS-501 mission. Nominal conditions at separation provided the basis for each run. This study covered range and range rate versus time from separation for S-IVB/CSM separation in time base (TB)5 and time base (TB)7*. For cases considered in this reference, the problem of recontact was not evident.

3.2 CM/SM SEPARATION - ENTRY PHASE

Reference 3 presents an analysis of this separation. In this analysis, it was shown that the probability of an eventual recontact between the CM and SM is very small. The only chance of a recontact occurring is if the SM fails to spin up and trims with its lift vector up in the orbital plane, and the CM flies a lift vector down, 10g controlled trajectory.

The possibility of recontact during entry for the nominal mission exists because the ballistic coefficient ratio of the SM to CM (1.072) falls between 0.88 and 1.16. This condition will occur whenever the SM entry weight is between approximately 16,000 and 22,000 pounds. The result of this condition is that sufficient range displacement during entry to insure no possibility of recontact for all lift profiles of the CM and SM cannot be achieved.

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*TB7 begins at second S-IVB burn cutoff.

4. ALTERNATE MISSIONS (MODE IV ABORTS)

The types of alternate missions are discussed in Reference 4.

4.1 ALTERNATE MISSIONS DURING FIRST S-IVB BURN

4.1.1 CSM/S-IVB Separation

Reference 5 requested that a CSM/S-IVB separation and recontact analysis be made for this alternate mission. The CSM and S-IVB time lines that were used are as follows:

CSM Time Line	Time (sec)
TB5 Start, S-IVB cutoff, Separation command, Start direct ullage	0.0
Physical separation	1.7
End direct ullage, Start +X translation	3.0
End +X translation, Start SPS burn orientation	10.0
SPS ignition	100.0
S-IVB Time Line	
TB5 Start, S-IVB Cutoff	0.0
Start S-IVB ullage	0.3
Start continuous vent	59.0
End S-IVB ullage	88.0

Mass characteristics, performance, and venting data are taken from References 4, 6, 7, and 8 and are as follows:

S-IVB Weight	228,800 lb
CSM Weight	51,762 lb
S-IVB Ullage Force	140 lb (constant)
SM/RCS Thrust	398.4 lb

S-IVB Venting Thrust

Time (sec)	Thrust (lb)
0	55
5	52
15	50
50	47

Relative displacement between the CSM and S-IVB is presented in Figure 4. 1-1, for the two cases in which the S-IVB ullage is on and commanded off. There is no recontact for either case.

4. 1. 2 CM/SM Separation - Entry Phase

This separation was analyzed in Reference 3. It was shown that no problems of recontact exist for this type of alternate mission. Since the ballistic coefficient* of the CM (78. 7) is considerably greater than that of the SM (41. 2 to 47. 3) for alternate missions during the first S-IVB burn, the CM flies ahead of the SM with sufficient range displacement during entry such that regardless of the lift profiles of the CM and SM, no recontact is possible.

4. 2 ALTERNATE MISSION DURING PARKING ORBIT

4. 2. 1 CSM/S-IVB Separation

The analysis of Section 4. 1. 1 of this report is applicable to this separation. No recontact problems are present.

4. 2. 2 CM/SM Separation - Entry Phase

This separation was analyzed in Reference 3. No recontact problems are indicated for this type of alternate mission. Since the ballistic number of the CM (78. 7) is greater than that of the SM (47. 3) for an alternate mission during the parking orbit, the CM flies ahead of the SM with sufficient range displacement during entry such that regardless of the lift profiles of the CM and SM, no recontact is possible.

*In this report, ballistic coefficients are given in units of $\mathrm{lbf/ft^2} \left(\frac{W}{C_D A}\right)$.

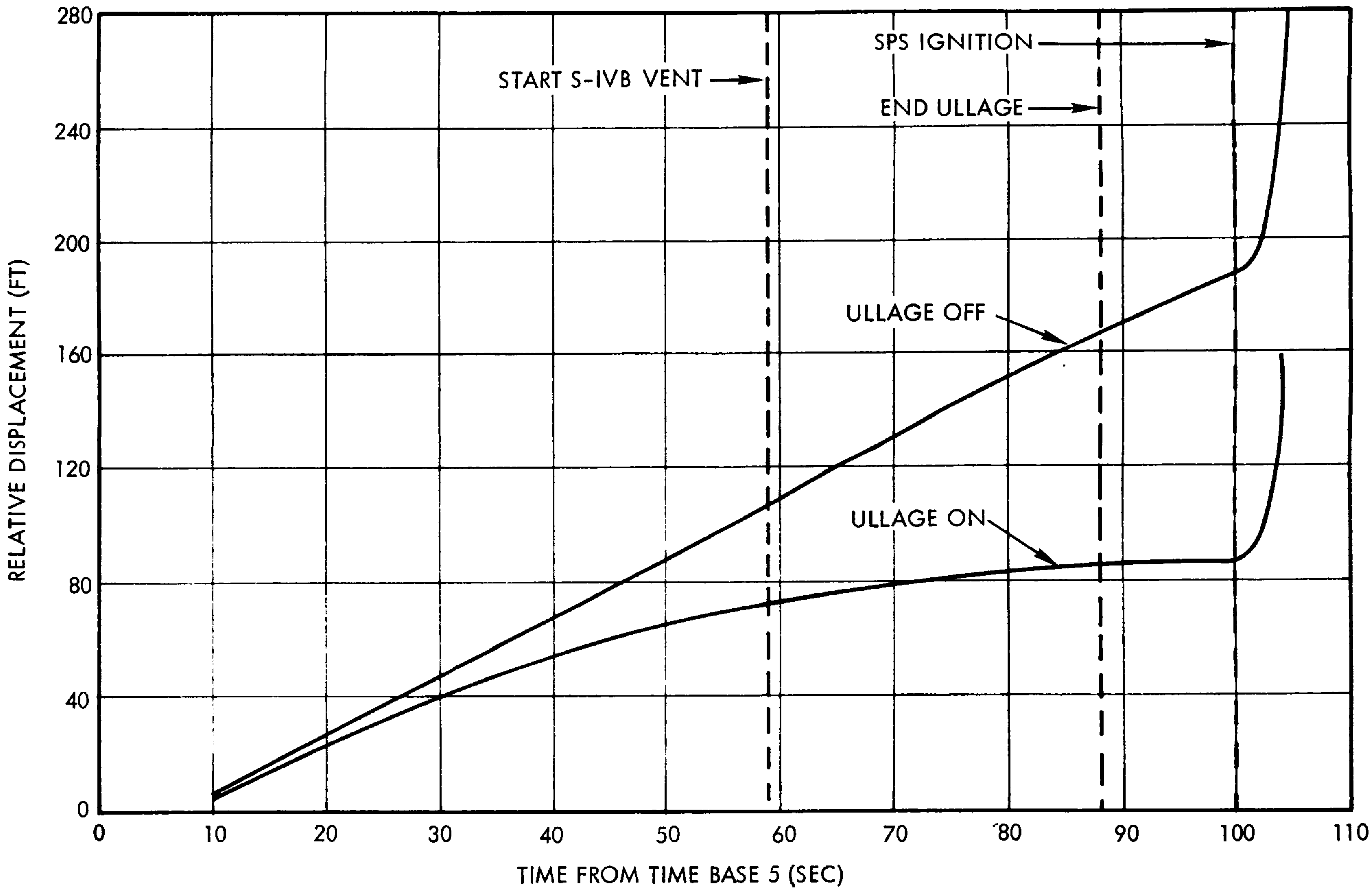

Figure 4.1-1. Alternate Mission, CSM/S-IVB Displacement

4.3 ALTERNATE MISSIONS DURING SECOND S-IVB BURN

4.3.1 CSM/S-IVB Separation

The analysis of Reference 2 may be applied since this study covered range and range rate versus time from separation for CSM/S-IVB separation in TB7 after S-IVB second burn. That analysis determined that there are no recontact problems for this separation and alternate mission sequence.

4.3.2 CM/SM Separation - Entry Phase

The probability of an eventual recontact between the CM and SM is very small as discussed in Reference 3, but exists because the ballistic coefficient ratio of the SM to CM (the ratio varies from 0.523 to 2.103 depending on the SM entry weight) falls between 0.88 and 1.16 for certain alternate missions during the second S-IVB burn. This condition results in insufficient range displacement during entry to insure no possibility of recontact for all lift profiles of the CM and SM. However, the conditions that must exist for the recontact to occur are (1) the SM fails to spin up after separation, (2) the SM trims with its lift vector up in the orbital plane, and (3) the CM flies a lift vector down, 10g controlled trajectory.

5. ABORTED MISSIONS

The types of aborted missions are discussed in Reference 9.

5.1 LAUNCH PHASE, NO SPS BURN ABORTS

5.1.1 CSM/S-IVB Separation

References 10 and 11 discuss launch phase aborts (Mode III and Mode II, respectively) in which there are no SPS ignitions. Each analysis concluded that recontact between the CSM and S-IVB will occur if the S-IVB is allowed to ullage after TB5.

For Mode II aborts, where the SPS burn is inhibited because of TFF interrupt due to early staging of the S-II to the S-IVB, no CSM/S-IVB recontact will occur immediately after separation during the orientation maneuver; however, during the coast-to-entry phase, recontact is possible from approximately 56 to 71 seconds after separation. The exact time of recontact will depend on the time of abort and the SLA panel opening angle (34 to 50 degrees). A recommended solution is to command the S-IVB ullage off.

The analysis in Reference 10 indicates that recontact between the CSM and S-IVB will occur at TB5 + 112.5 seconds unless the S-IVB ullage is commanded off at TB5 + 0.0 seconds. This would result in a separation range of approximately 130 feet at TB5 + 112.5 seconds and insure no recontact.

5.1.2 CM/SM Separation - Entry Phase

This separation was analyzed in Reference 3. It was determined that no recontact problem is present for these aborts. Since the ballistic coefficient of the CM (78.7) is considerably less than that of the SM (171.0) for a launch phase, no SPS burn abort, the CM will fly behind the SM with sufficient range displacement during entry so that regardless of the lift profiles of the CM and SM, no recontact is possible.

5.2 MODE II ABORTS

5.2.1 CSM/S-IVB SEPARATION

Reference 5 requested that a study be made to determine if there is a possibility of a recontact using the presently defined CSM and S-IVB time lines.

Reference 11 discusses early Mode II aborts in which there are no SPS ignitions as a result of TFF interrupts (time-of-free-fall to entry interface is less than 200 seconds), and concludes that recontact between the S-IVB and CSM will occur if the S-IVB is allowed to ullage immediately after TB5. Therefore, it was recommended in Reference 11 that the S-IVB ullage be commanded off. Reference 10 verifies that no recontact problem exists when the ullage is commanded off.

The analysis of Section 5. 3. 1 can be applied to those Mode II aborts which incorporate an SPS burn. The results (Figure 5. 3-1) indicate that for a minimum SPS burn (0. 7 seconds) initiated at TB5 + 6. 0 seconds, no CSM/S-IVB recontact occurs.

5. 2. 2 CM/SM Separation - Entry Phase

This separation is analyzed in Reference 3, where it is shown that there are no recontact problems. During Mode II aborts, the ballistic coefficient of the CM (78. 7) is smaller than that of the SM (118. 1 to 171. 0); therefore, the CM will fly behind the SM with sufficient range displacement during entry so that regardless of the lift profiles of the CM and SM, no recontact is possible.

5. 3 MODE III ABORTS

5. 3. 1 CSM/S-IVB Separation

The analysis in Reference 5 indicates that Mode III aborts may have recontact problems during a no SPS burn condition where the CMC Mode III targeting is satisfied at S-IVB cutoff. The CSM and S-IVB sequence of events are as follows:

CSM Time Line	Time (sec)
TB5 start, S-IVB cutoff, Separation command, Start direct ullage	0. 0
Physical separation	1. 7
End direct ullage, start +X translation	3. 0
End +X translation, SPS ignition	6. 0
SPS off (minimum time)	6. 7

S-IVB Time Line	Time (sec)
TB5 start, S-IVB cutoff	0.0
Start S-IVB ullage	0.3
Start continuous vent	59.0
End S-IVB ullage	88.0

Mass characteristics, performance, and venting data are taken from References 6, 7, 8, and 9 and are as follows:

S-IVB Weight	228,800 lb
CSM Weight	51,762 lb
S-IVB Ullage Force	140 lb (constant)
SM/RCS Thrust	398.4 lb
SPS Thrust	21,500 lb
S-IVB Venting Thrust	

Time (sec)	Thrust (lb)
0.0	55.0
5.0	52.0
15.0	50.0
50.0	47.0

The resulting relative displacement is shown in Figure 5.3-1. The minimum SPS thrusting allowed by the guidance computer (CMC) is sufficient to preclude CSM and S-IVB recontact.

Reference 10 analyzes the effect on relative motion of an SPS ignition failure during a Mode III abort. Recontact between the S-IVB and CSM is indicated if the S-IVB is allowed to ullage at TB5. Commanding the S-IVB ullage off eliminates the recontact problem.

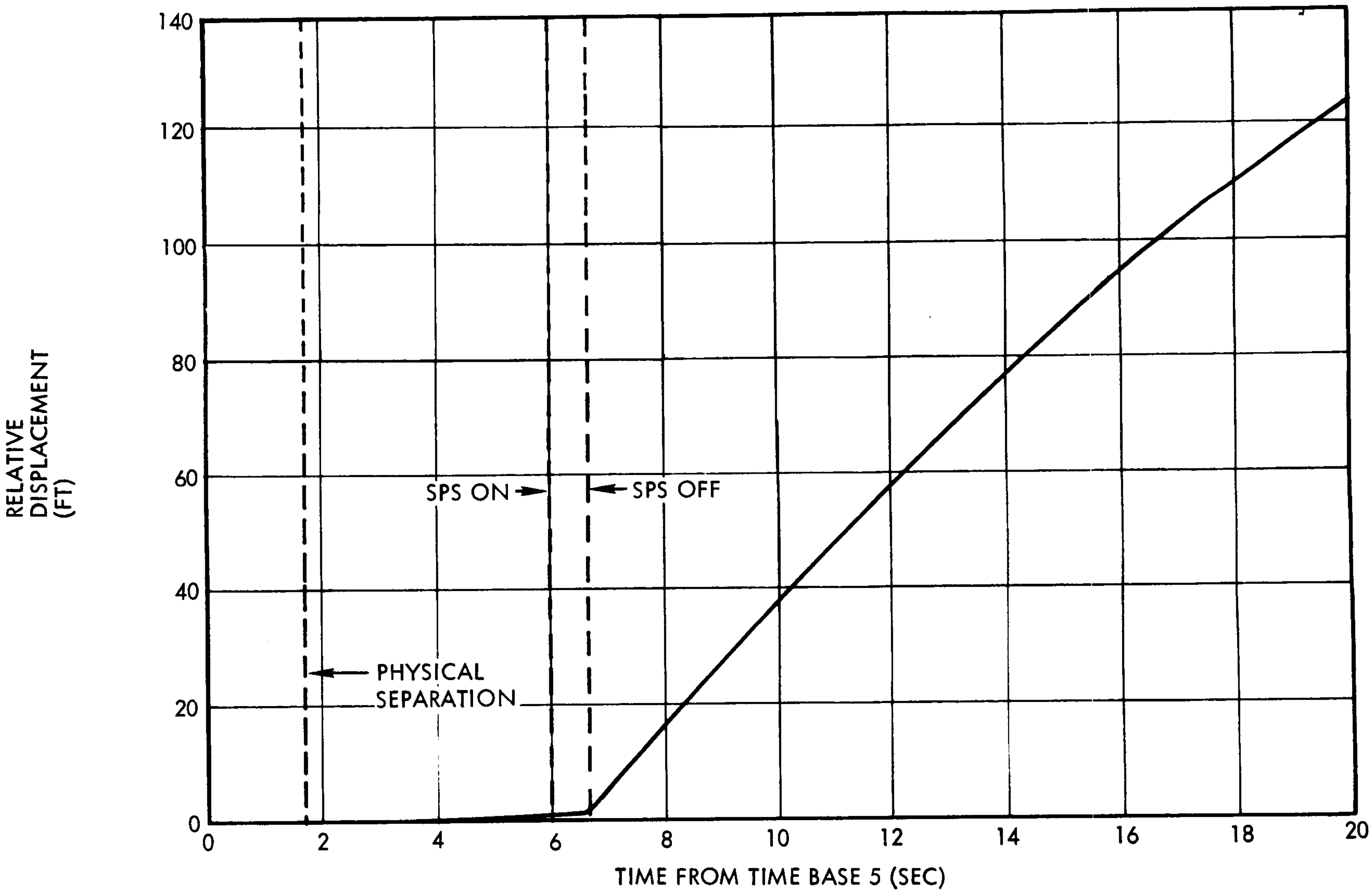

Figure 5. 3-1. Mode III Abort, CSM/S-IVB Relative Displacement

5.3.2 CM/SM Separation - Entry Phase

This separation is analyzed in Reference 3. A recontact during early Mode III aborts is possible only if the SM fails to spin up and trims with its lift vector up in the orbital plane while the CM flies a ballistic entry. The recontact possibility exists because the ballistic coefficient ratio of the CM to SM (the ratio varies from 1.110 to 2.171 depending on SM entry weight) falls between 0.88 and 1.16 for early Mode III aborts. This condition results in insufficient range displacement during entry to insure no possibility of recontact for all lift profiles of the CM and SM.

5.4 ABORTS DURING PARKING ORBIT (NO SECOND S-IVB BURN)

5.4.1 CSM/S-IVB Separation

5.4.1.1 SPS Deorbit

Reference 5 requests that a safe and simple procedure be established for this deorbit maneuver. Based on previous studies (References 9 and 12) and applicable restrictions (References 5, 9, and 13), the following constraints must be adhered to:

1) Separation will be achieved by direct ullage commanded by the ground. Such an ullage must not invalidate the B-MAG attitude reference.

2) Command tracking stations must have radar contact from the beginning of the deorbit until the CM reaches an altitude of 400,000 feet. This requires the deorbit to be performed over the U.S..

3) Nominal time to orient the CSM to the deorbit attitude is 5 minutes. This means that the CSM should be placed in deorbit attitude prior to reaching the West Coast command tracking stations.

4) The SPS deorbit burn will last for 40 seconds at an attitude of 140 degrees below the inertial velocity vector.

Therefore, the following separation and deorbit procedure is recommended:

1) CSM/S-IVB separation command by Carnarvon followed by ten seconds of direct ullage in a zero-degree posigrade direction with physical separation occuring after 1.7 seconds.

2) Coast to signal acquisition by Hawaii where CSM is placed into deorbit attitude.

3) Coast until 100 seconds after signal acquisition by West Coast command tracking stations at which time attitude corrections are made and after which the SPS is ignited for the deorbit maneuver.

The relative separation distance of the CSM with respect to the S-IVB using the above sequence is presented in Figure 5.4-1. This sequence presents no recontact problems.

5.4.1.2 RCS Deorbit

This deorbit maneuver is discussed in Reference 9. To avoid a CSM/S-IVB recontact problem, it was determined that a minimum time of 370 seconds is required from separation to RCS ignition. Reference 9 presents parametric data so that a trade off study between deorbit attitude and impact point can be made.

5.4.2 CM/SM Separation - Entry Phase

An analysis of this separation is presented in Reference 3. There are no recontact problems for either the SPS or RCS deorbit maneuver. Since the ballistic coefficient of the CM (78.7) is considerably smaller than that of the SM (159.1 or 167.4) for aborts during the parking orbit, the CM flies behind the SM with sufficient range displacement during entry so that regardless of the lift profiles of the CM and SM, no recontact is possible.

5.5 ABORTS DURING SECOND S-IVB BURN

5.5.1 CSM/S-IVB Separation

The analysis of Reference 2 is applicable to this separation, and shows that there are no recontact problems. Range and range rate plots

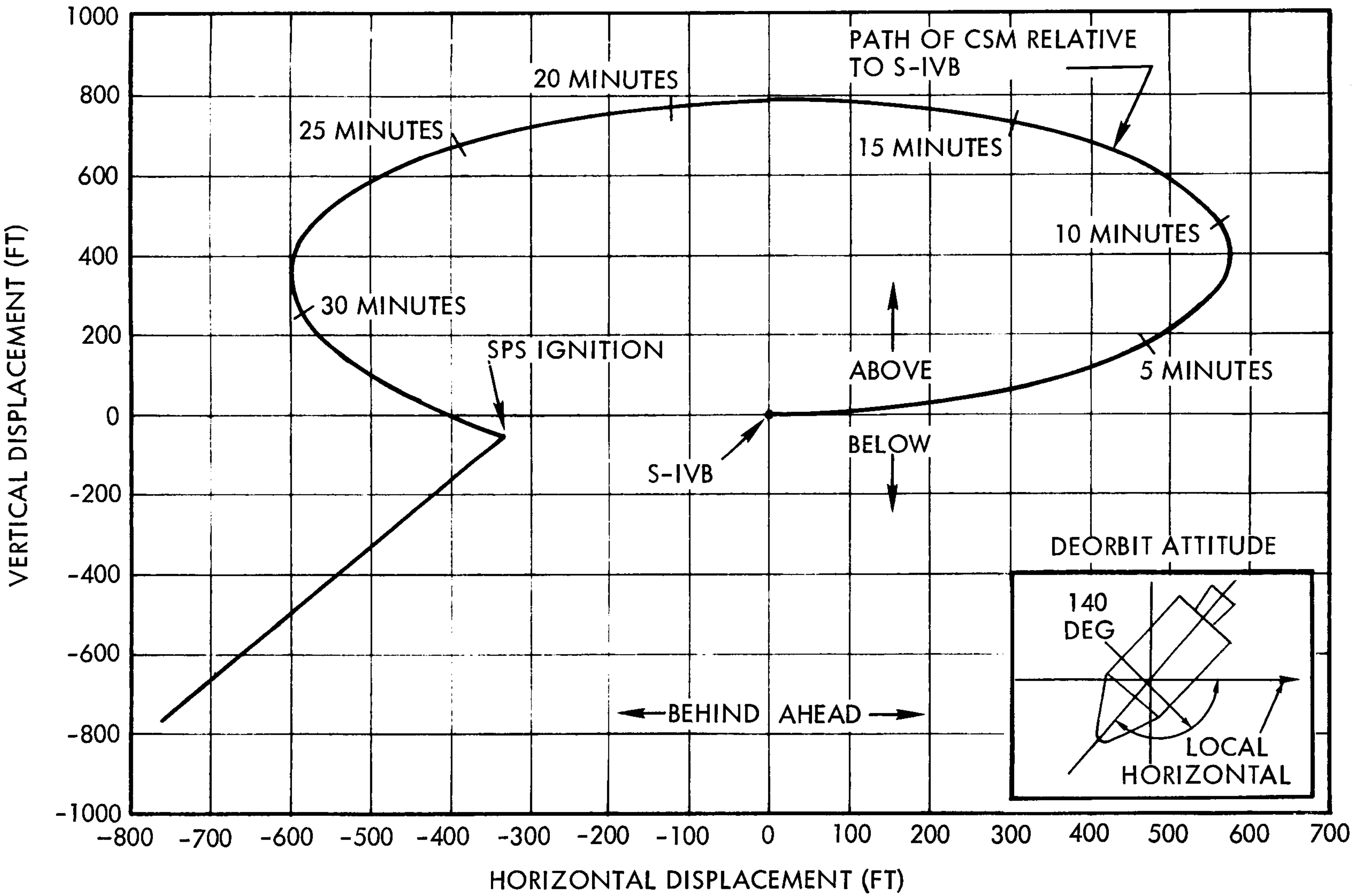

Figure 5.4-1. SPS Deorbit from Parking Orbit

indicate that adequate separation distance is obtained for the TB7 separation sequence.

5.5.2 CM/SM Separation - Entry Phase

Reference 3 concludes that no recontact problems exist during this entry phase. Since the ballistic coefficient of the CM (78.7) is considerably less than that of the SM (171.0), the CM flies behind the SM with sufficient range displacement during entry so that regardless of the lift profiles of the CM and SM, no recontact is possible.

5.6 ABORTS DURING SPS BURNS

The only separation requiring analysis for these aborts is the CM/SM separation which is discussed in Reference 3. The one region of possible recontact is during the entry phase for aborts occuring during the latter portion of the second SPS burn. The probability of recontact is small, but does exist in the event the SM fails to spin up and trims with its lift vector up in the orbital plane while the CM is commanded to fly a lift vector down, 10g controlled entry.

The possibility of recontact exists because the ballistic coefficient ratio of the SM to CM (The ratio varies from 1.072 to 2.171 depending on SM entry weight) falls between 0.88 and 1.16 for aborts occuring during the latter portion of the SPS burn. This condition results in insufficient range displacement during entry to insure no recontact possibility for all lift profiles of the CM and SM.

6. GENERAL STUDIES

6.1 SPS PLUME EFFECTS ON S-IVB

Reference 14 analyzed SPS plume impingement effects on the S-IVB during the CSM/S-IVB separation sequence. The analysis indicated that no excessive torques will be created on the S-IVB. For the separation sequence used in this analysis, the separation distance between the CSM and S-IVB will be approximately 101 feet at SPS ignition. This will result in a dynamic pressure of approximately 3 lb/ft^2. The sequence used for separation was an RCS +X translation for 4.3 seconds followed by a CSM coast of 90 seconds.

6.2 S-IVB OVERSPEED

Reference 15 indicates a possible CSM/S-IVB recontact problem resulting from an S-IVB overspeed at injection. Analysis given in Reference 9 indicates that no recontact problem exists in the event of such an overspeed. This analysis considered a maximum S-IVB overspeed burn time of approximately 26.7 seconds ($+3\sigma$) and a minimum of approximately 5.4 seconds (-3σ). Nominal separation and coast sequences were used, including the orientation of the spacecraft to the solar soak attitude prior to CSM/S-IVB separation. The results indicate that if the S-IVB is allowed to burn to propellant depletion, the possibility of recontact is minimized because separation is out-of-plane. The minimum separation distance between the CSM and S-IVB for this procedure is approximately 100 feet.

6.3 G AND N FAILURE

Reference 16 requested that an analysis be performed to determine which of the following is the better CM/SM separation attitude in the event a G and N failure occurs prior to, at, or just after the completion of the second SPS burn: entry attitude or SPS burn attitude. In this failure mode, the possible CM entries are full lift up, constant bank angle, or rolling entry. For the full lift and rolling entry cases only, comparison of relative separation distance is made between separations performed in the SPS burn attitude and entry attitude. The constant bank angle cases were not considered due to the CM moving out of the entry plane of the SM.

The results presented in Figures 6.3-1 and 6.3-2 show the paths of the CM relative to the SM for separation sequences beginning immediately after orientation for the second SPS burn and at the time of second SPS ignition, respectively. These figures show that at either time, CM/SM separation can be performed in either the SPS burn attitude or the entry attitude with no CM/SM recontact during the entry phase. Therefore, if a G and N failure is present prior to or at second SPS ignition, CM/SM separation may be made in either the SPS burn attitude or the entry attitude.

The results presented in Figures 6.3-3 and 6.3-4 show similar relative position data for separation sequences commencing immediately after a full-second SPS burn. These figures show that CM/SM separation in the entry attitude produces a more favorable relative position of the two bodies.

Therefore, it is recommended that in the event of a G and N failure, the CM/SM separation be performed in the entry attitude. This separation attitude has the added advantage of more easily controlled body rates, since it will entail a pitch rotation to entry attitude with the CSM. Separation in the burn attitude will require rotation of the CM alone to the entry attitude. The lower pitch inertia of the CM may tend to produce higher, harder to control body rates.

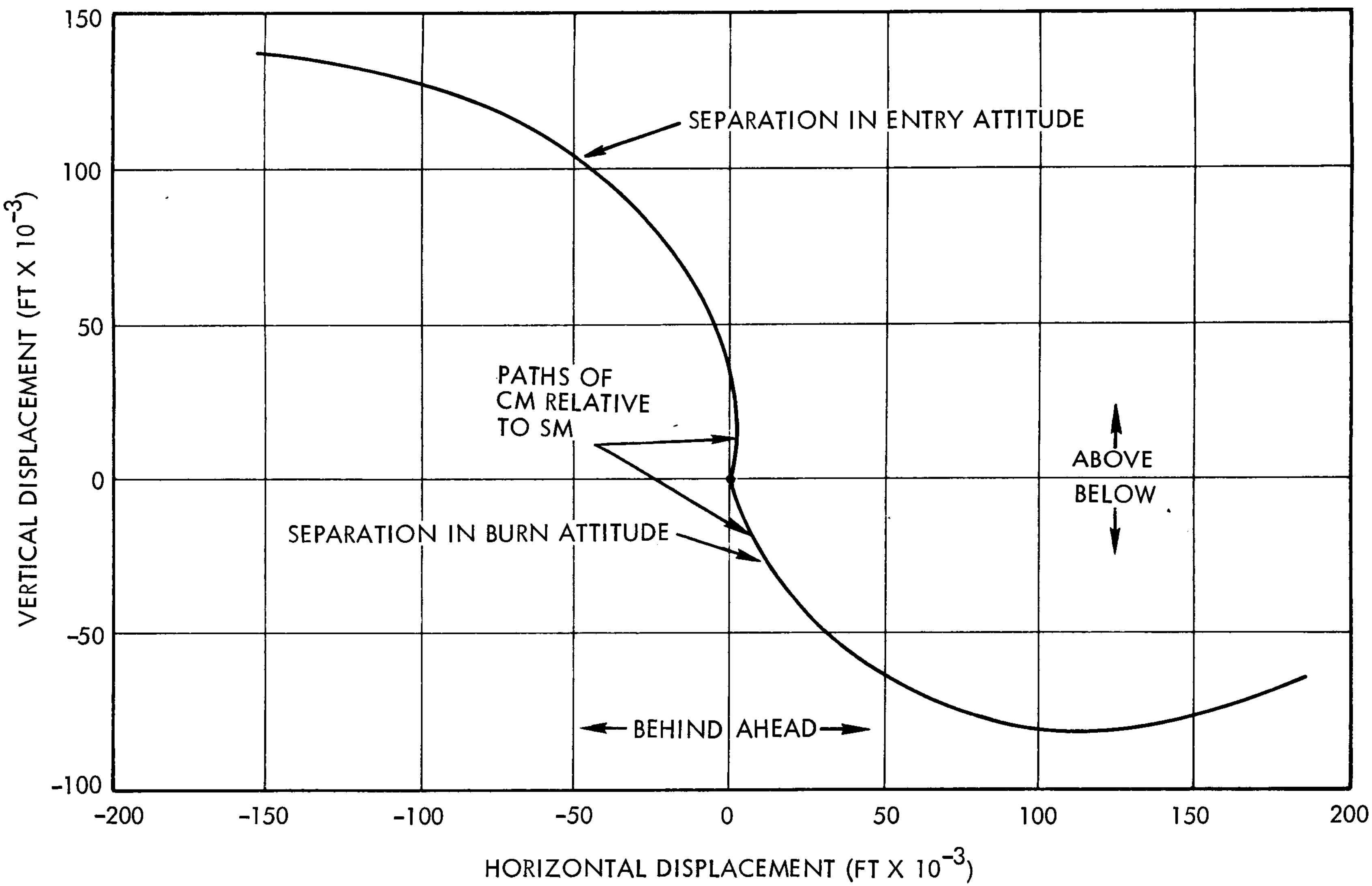

Figure 6. 3-1. CM/SM Separation After Orientation for Second SPS Burn

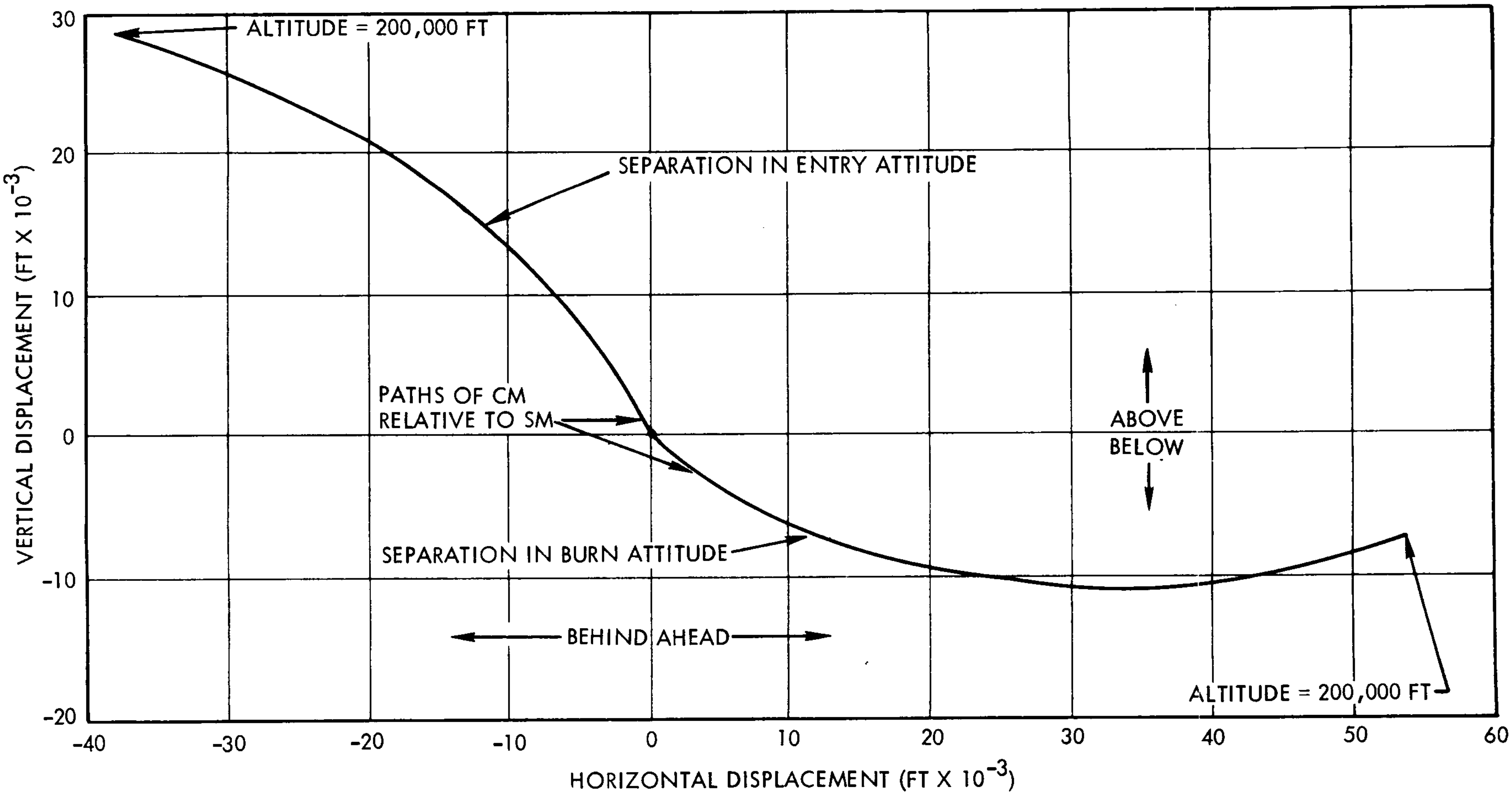

Figure 6.3-2. CM/SM Separation at the Time of Second SPS Ignition

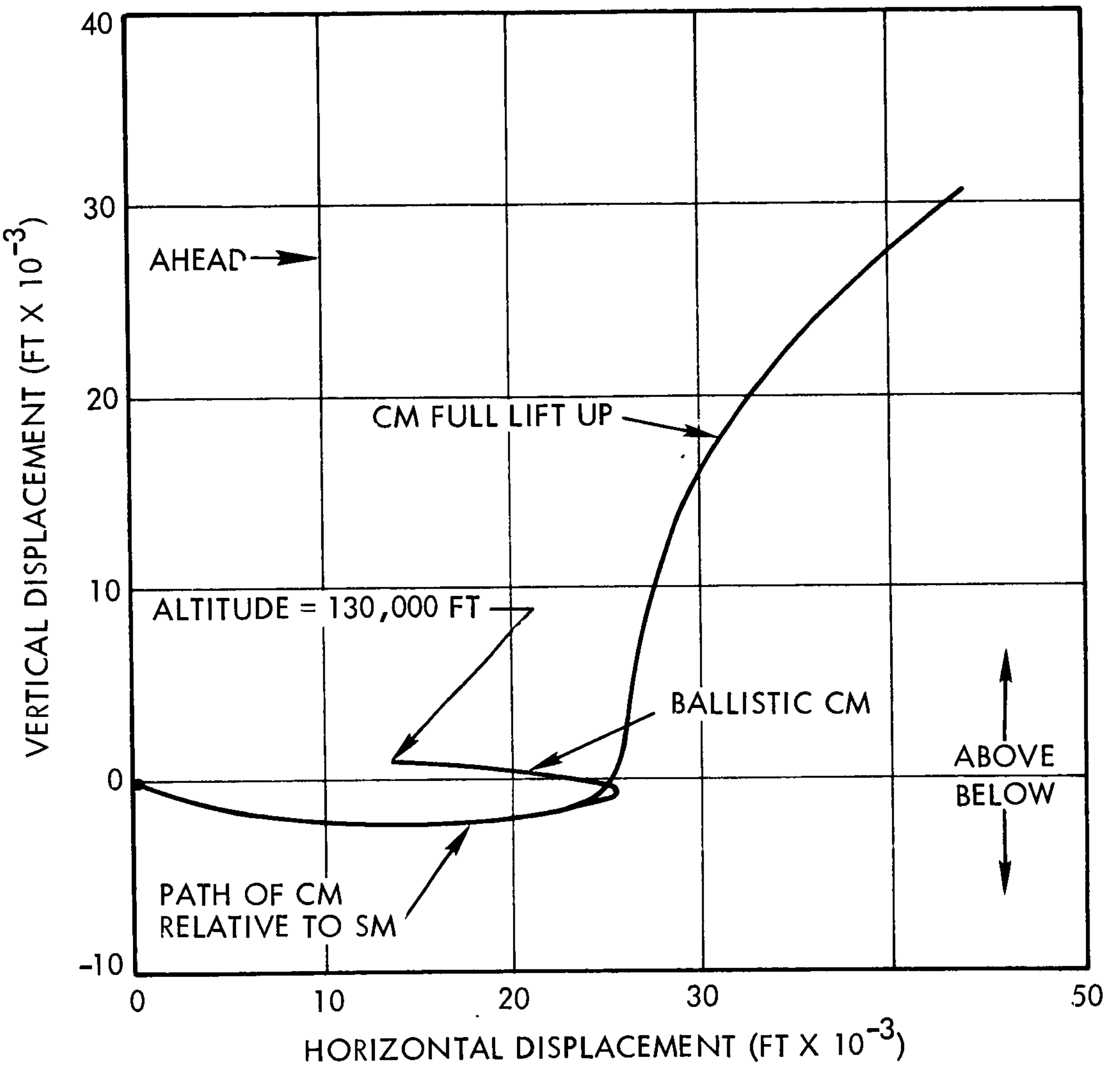

Figure 6.3-3. CM/SM Separation in Burn Attitude After a Full Second SPS Burn

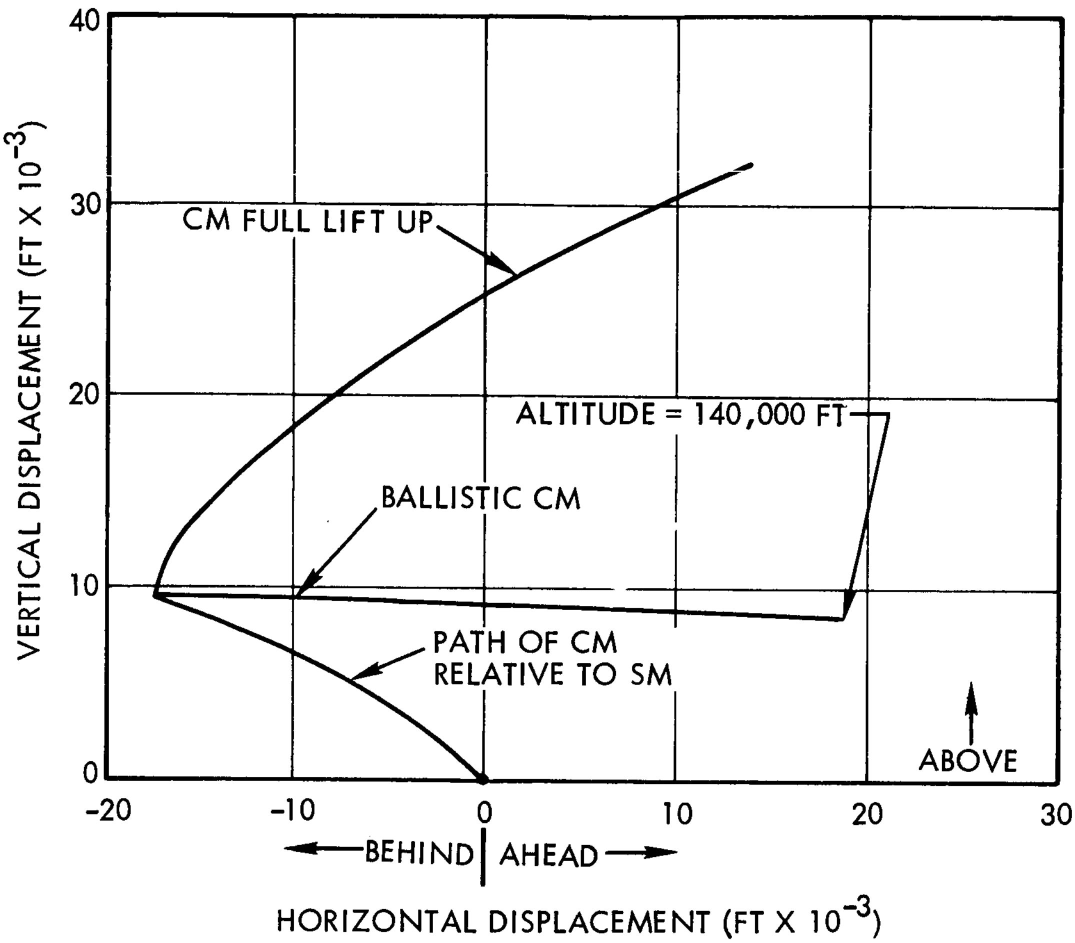

Figure 6.3-4. CM/SM Separation in Entry Attitude After a Full Second SPS Burn

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